

# Detecting *tāla* Computationally in Polyphonic Context - A Novel Approach

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## Abstract

In North-Indian-Music-System(NIMS), *tablā* is mostly used as percussive accompaniment for vocal-music in polyphonic-compositions. The human auditory system uses perceptual grouping of musical-elements and easily filters the *tablā* component, thereby decoding prominent rhythmic features like *tāla*, tempo from a polyphonic-composition. For Western music, lots of work have been reported for automated drum analysis of polyphonic-composition. However, attempts at computational analysis of *tāla* by separating the *tablā*-signal from mixed signal in NIMS have not been successful. *Tablā* is played with two components - right and left. The right-hand component has frequency overlap with voice and other instruments. So, *tāla* analysis of polyphonic-composition, by accurately separating the *tablā*-signal from the mixture is a baffling task, therefore an area of challenge. In this work we propose a novel technique for successfully detecting *tāla* using left-*tablā* signal, producing meaningful results because the left-*tablā* normally doesn't have frequency overlap with voice and other instruments. North-Indian-rhythm follows complex cyclic pattern, against linear approach of Western-rhythm. We have exploited this cyclic property along with stressed and non-stressed methods of playing *tablā*-strokes to extract a characteristic pattern from

the left-*tablā* strokes, which, after matching with the grammar of *tāla*-system, determines the *tāla* and tempo of the composition. A large number of polyphonic(vocal+*tablā*+other-instruments) compositions has been analyzed with the methodology and the result clearly reveals the effectiveness of proposed techniques.

**Keywords:** Left-*tablā* drum , *Tāla* detection, Tempo detection, Polyphonic composition, Cyclic pattern, North Indian Music System

## 1 Introduction

Current research in Music-Information-Retrieval(MIR) is largely limited to Western music cultures and it does not address the North-Indian-Music-System hereafter NIMS, cultures in general. NIMS raises a big challenge to current rhythm analysis techniques, with a significantly sophisticated rhythmic framework. We should consider a knowledge-based approach to create the computational model for NIMS rhythm. Tools developed for rhythm analysis can be useful in a lot of applications such as intelligent music archival, enhanced navigation through music collections, content based music retrieval, for an enriched and informed appreciation of the subtleties of music and for pedagogy. Most of these applications deal with music compositions of polyphonic kind in the

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context of blending of various signals arising from different sources. Apart from the singing voice, different instruments are also included.

As per [1] rhythm relates to the *patterns of duration* that are phenomenally present in the music. It should be noted that these *patterns of duration* are not based on the actual duration of each musical event but on the Inter Onset Interval (IOI) between the attack points of successive events. As per [2], an accent or a stimulus is marked for consciousness in some way. Accents may be phenomenal, i.e. changes in intensity or changes in register, timbre, duration, or simultaneous note density or structural like arrival or departure of a cadence which causes a note to be perceived as accented. It may be metrical accent which is perceived as accented due to its metrical position [3]. Percussion instruments are normally used to create accents in the rhythmic composition. The percussion family which normally includes timpani, snare drum, bass drum, cymbals, triangle, is believed to include the oldest musical instruments, following the human voice [4]. The rhythm information in music is mainly and popularly provided by the percussion instruments. One simple way of analyzing rhythm of a composite or polyphonic music signal having some percussive component, may be to extract the percussive component from it using some source separation techniques based on frequency based filtering. Various attempts have been made in Western music to develop applications for re-synthesizing the drum track of a composite music signal, identification of type of drums played in the composite signal [ex. the works of [5, 6] etc., described in Section 3 in detail]. Human listeners are able to perceive individual sound events in complex compositions, even while listening to a polyphonic music recording, which might include unknown timbres or musical instruments. However designing an automated system for rhythm detection from a polyphonic music composition is very difficult.

In the context of NIMS rhythm popularly known as *tāla*, *tablā* is the most popular percussive instrument. Its right hand drum-*dayan* and left hand drum-*bayan* are played together and amplitude-peaks spaced at regular time intervals, are created by playing every stroke. One way of rhythm information retrieval

from polyphonic composition having *tablā* as one of the percussive instruments, may be to extract the *tablā* signal from it and analyze it separately. The *dayan* has a frequency overlap with other instruments and mostly human-voice for polyphonic music, so if we extract the whole range of frequencies for both *bayan* and *dayan* components, by existing frequency based filtering methods, the resultant signal will be a noisy version of original song as it will still have part of other instruments, human voice components along with *tablā*. Also conventional source separation methods lead to substantial loss of information or sometimes addition of unwanted noise. This is the an area of challenge in *tāla* analysis for NIMS. Although, NIMS *tāla* functions in many ways like Western meter, as a periodic, hierarchic framework for rhythmic design, it is composed of a sequence of unequal time intervals and has longer time cycles. Moreover *tāla* in NIMS is distinctively cyclical and much more complex compared to Western meter [7]. This complexity is another challenge for *tāla* analysis.

Due to the above reasons defining a computational framework for automatic rhythm information retrieval for North Indian polyphonic compositions is a challenging task. Very less work has been done for rhythmic information retrieval from a polyphonic composition in NIMS context. In Western music, quite a few approaches are followed for this purpose, mostly in the areas of beat-tracking, tempo analysis, annotation of strokes/pulses from the separated percussive signal. We have described these systems in the Section 3. For NIMS, very few works of rhythm analysis are done by adopting Western drum-event retrieval system. These works result in finding out meter or speed which are not very significant in the context of NIMS. Hence this is an unexplored area of research for NIMS.

In this work we have proposed a completely new approach, i.e. instead of extracting both *bayan* and *dayan* signal, we have extracted the *bayan* signal from the polyphonic composition by using band-pass filter. This filter extracts lower frequency part which normally does not overlap with the frequency of human voice and other instruments in a polyphonic composition. Most of the *tāla*-s start with a *bol* or stroke which has a *bayan* component (either played with

*bayan* alone or both *bayan* and *dayan* together) and also the some consequent section(*vibhāga* in NIMS terminology) boundary-*bol*-s have similar *bayan* component. Hence these strokes would be captured in the extracted *bayan* signal. For a polyphonic composition, its *tāla* is rendered with cyclically recurring patterns of fixed time-lengths. This is the cyclic property of NIMS, discussed in detail in section 2. So after extracting the starting *bol*-s and the section boundary strokes from the *bayan* signal, we can exploit the cyclic property of a *tāla* and the pattern of strokes appearing in a single cycle and can detect important rhythm information from a polyphonic composition. This would be a positive step towards rhythm information retrieval from huge collection of music recordings for both film music and live performances of various genres of *hindi* music. Here, we consider the *tāla* detection of different single-channel, polyphonic clips of *hindi* vocal songs of devotional, semi-classical and movie soundtracks from NIMS, having variety of tempo and *mātrā*-s.

The rest of the paper is organized as follows. A review of past work is presented in section 3. Some definitions are provided in section 2. In section 4 the proposed methodology is elaborated. Experimental results are placed in section 5 and the paper ends with concluding remarks in section 6.

## 2 Definitions

### 2.1 *Tāla* and its structure in NIMS

The basic identifying features of rhythm or *tāla* in NIMS are described as follows.

- ***Tāla* and its cyclicity:** North Indian music is metrically organized and it is called *nibaddh*(bound by rhythm) music. This kind of music is set to a metric framework called *tāla*. Each *tāla* is uniquely represented as cyclically recurring patterns of fixed time-lengths.
- ***Āvart*:** This recurring cycle of time-lengths in a *tāla* is called *āvart*. *Āvart* is used to specify the number of cycles played in a composition, while annotating the composition.

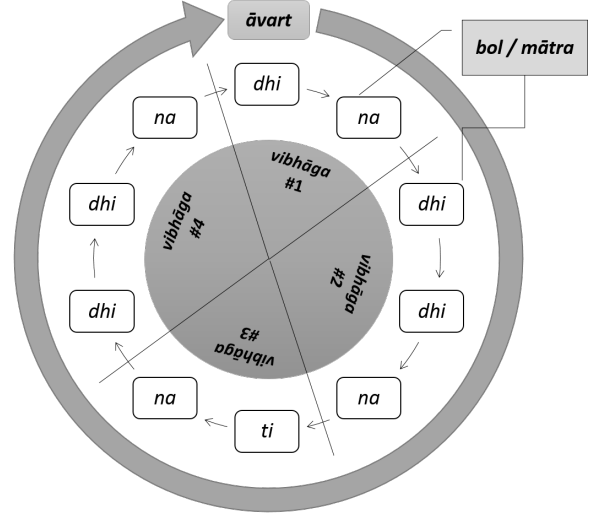


Figure 1: The hierarchy of NIMS *tāla* illustrated with *jhaptal*

- ***Mātra*:** The overall time-span of each cycle or *āvart* is made up of a certain number of smaller time units called *mātra*-s. The number of *mātra*-s for the NIMS *tāla*-s, usually varies from 6 to 16.
- ***Vibhāga*:** The *mātra*-s of a *tāla* are grouped into sections, sometimes with unequal time-spans, called *vibhāga*-s.
- ***Bol*:** In the *tāla* system of North Indian music, the actual articulation of *tāla* is done by

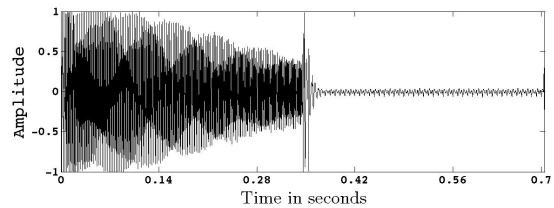


Figure 2: *ta*\*(absent-*bol*)

certain syllables which are the mnemonic names of different strokes/pulses corresponding to each *mātra*. These syllables are called *bol*-s. There are four types of *bol*-s as defined below.

1. **Sam:** The first *mātrā* of an *āvart* is referred as *sam* which is mandatorily stressed [8].
2. **Tālī-bol:** *Tālī-bol*-s are usually stressed, whereas *khali*-s are not. *Tālī-bol*-s are gestured by the *tablā* player with claps of the hands, hence are called *sasabda kriya*. The *sam* is almost always a *Tālī-bol* for most of the *tāla*-s, with only exception of *rupak tāla* which designates the *sam* with a moderately stressed *bol* called *khali* (as explained below) [9].

Highly stressed *vibhāga* boundaries are indicated through the *tālī-bols* [9]. *Tālī-sam* is indicated with a (+) in the rhythm notation of NIMS. Consequent *Tālī-vibhāga*-boundaries are indicated with 2, 3, ...

3. **Khali-bol:** *Khali* literally means empty and for NIMS it implies wave of the hand or *nisabda kriya*. Moderately stressed *Vibhāga* boundaries are indicated through the *khali-bols* so we almost never find the *khali* applied to strongly stressed *bol*-s like *sam* [9]. *khali-sam* is indicated with a (0) in the rhythm notation of NIMS and consequent *khali-vibhāga*-boundaries are indicated also with 0.
4. **Absent-bol:** Sometimes while playing *tablā*, certain *bol*-s are dropped maintaining the perception of rhythm intact. They are called rests and they have equal duration as a *bol*. We have termed them as absent strokes/*bol*-s. These *bol*-s are denoted by \* in the rhythm notation of a NIMS composition Ancient-future. In the Figure 2, the waveform of absent *bol*, denoted by \*, is shown just after another *bol ta*, played in a *tablā*-solo.  
Normally in a NIMS composition there may be many absent *bol*-s in the *thekā* played for

the *tāla*. In these cases other percussive instruments (other than *tablā*) and vocal emphasis might generate percussive peaks for the time positions of the absent strokes, depending on the composition, the lyrics being sung and thus the rhythm of the composition is maintained.

- **Thekā:** For *tablā*, the basic characteristic pattern of *bol*-s that repeats itself cyclically along the progression of the rendering of *tāla* in a composition, is called *thekā*. In other words it's the most basic cyclic form of the *tāla* [9]. Naturally *thekā* corresponds to the basic pattern of *bol*-s in an *āvart*. The strong starting *bol* or *sam* along with the *tālī-vibhāga*-boundaries in a *thekā* carries the main accent and creates the sensation of cadence and cyclicity.

#### Description of the definitions with an example:

The details of these theories are shown in the structure of a *tāla*, called *jhaptal* in the Table 1 and Figure 3. The hierarchy of the features and their inter-dependence are shown in the Figure 1. The cyclic property of *tāla* is evident here.

1. The first row of Table 1 shows the sequence of *tālī*-s and the *khali*-s in a *thekā* or *āvart* of *jhaptal*. In this row the *sam* is indicated with a (+) sign and it should be noted that for *jhaptal* it is a *tālī-bol*. The second *tālī-vibhāga*-boundary is denoted by (2) followed by a (0) as it is the first *khali-vibhāga*-boundary and then by one more *tālī* denoted by (3) in a single cycle or *thekā*.

The amplitude waveform of the same *thekā* is shown in the Figure 3. The *sam* is shown in the Figure as the first *bol dhi*. This clip of *jhaptal* is available in *Tabla Radio*.

2. The second row of the Table 1 shows the *bol*-s of *jhaptal* in its *thekā*. In the Figure 3 the waveform of all these *bol*-s of a single cycle of *jhaptal* are shown.
3. *Jhaptal thekā* comprises of ten *mātrā*-s which are shown as per their sequence in third row of Table 1.

## 2.2 *Tablā and bol-s*

Table 1: Description of *jhaptal*, showing the structure and the its basic *bol*-pattern or the *thekā*

<i>tālī</i>	+		2			0		3		
<i>bol</i>	<i>dhi</i>	<i>na</i>	<i>dhi</i>	<i>dhi</i>	<i>na</i>	<i>ti</i>	<i>na</i>	<i>dhi</i>	<i>dhi</i>	<i>na</i>
<i>mātrā</i>	1	2	3	4	5	6	7	8	9	10
<i>vibhāga</i>	1		2			3		4		
<i>āvart</i>	1									

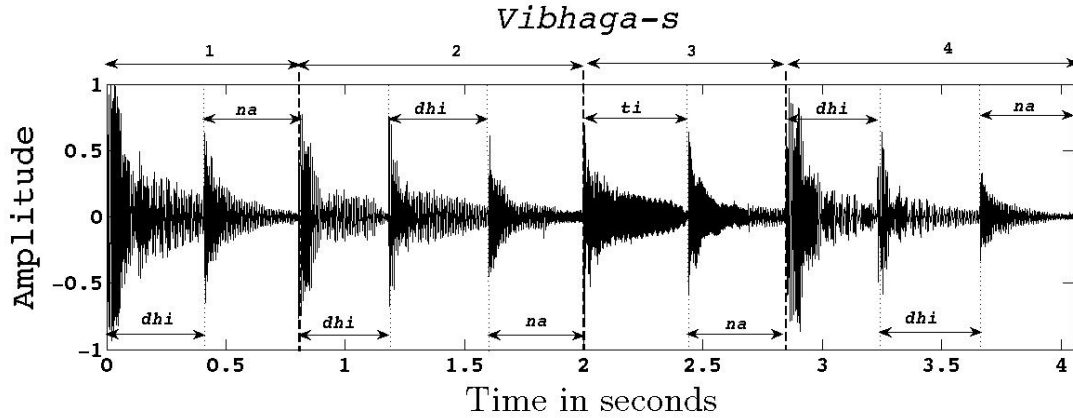


Figure 3: The basic pattern of *bol*-s for a single *āvart* or *thekā* of *jhaptal*

4. In the fourth row of the Table 1, the section or *vibhāga*-boundary-positions and sequences are shown. These *vibhāga*-sequences are shown for *jhaptal* in the Figure 3. We can see that there are four *vibhāga*-s in *jhaptal thekā* and first *vibhāga*-boundary is a *tālī-sam-bol dhi* having *mātrā* number as one. Second *vibhāga*-boundary is again *tālī-bol dhi* having *mātrā* number as three and so on.
5. In the fourth row of the Table 1, *āvart*-position and sequence is shown. As there is one cycle shown so *āvart*-sequence is 1.

## 2.2 *Tablā and bol-s*

*Tablā*, the traditional percussive accompaniment of NIMS, consists of a pair of drums. *Bayan* the left drum, is played by the left hand and made with metal

or clay. It produces loud resonant or damped non-resonant sound. As *bayān* can not be tuned significantly, when it is played, it produces a fixed range of frequencies. The *dayan* is the wooden treble drum, played by the right hand. A larger variety of acoustics is produced on this drum when tuned in different frequency ranges. In the *tālā* system of North Indian music, the representation of *tālā* is done mainly by playing *bol*-s on the *tablā*. *bol*-s as they are played in *tablā* are listed in Table 2. Figure 4, 5 and 6 shows the waveform of few sample waveforms of the *bol*-s *te*, *dha* and *ge* respectively. The clip of the *bol*-s are taken from *Tabla Radio*.

Most of the *tālā*-s have *tālī-sam* played either with *bayān* alone or with *bayān* and *dayan* played simultaneously [9]. Same thing happens for the *tālī vibhāga* boundaries. Most of the North Indian classical, semi-classical, devotional and popular songs are played as

### 2.3 Lay or tempo

Table 2: List of commonly played *bol*-s in either on *bayan* or *dayan* or together on both

played on <i>bayan</i>	played on <i>dayan</i>	played on both <i>bayan</i> and <i>dayan</i>
<i>ke, ge ,ghe ,kath</i>	<i>na, tin, tun, ti, te ,ta, da</i>	<i>dha (na + ge), dhin (tin + ge), dhun (tun + ge), dhi (ti + ge)</i>

per the *tāla*-s in Table 3. The most commonly played *thekā*-s are shown in this Table, Ref.Tabla Class; TAALMALA-THE RHYTHM OF MUSIC. For our experiment, we have considered the *thekā*-s listed in the Table 3 for the *tāla*-s *dadra, kaharba, rupak* and *bhājani*. For these *thekā*-s, the stressed *bol*-s having a *bayan* component is shown in **bold** and pipes in **bold** indicate *vibhāga* boundary.

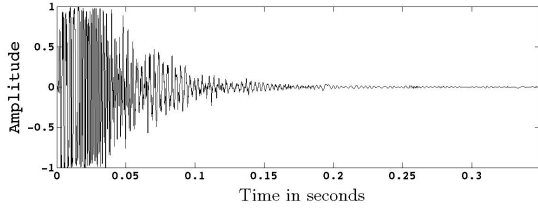


Figure 4: *te(dayan)-bol*

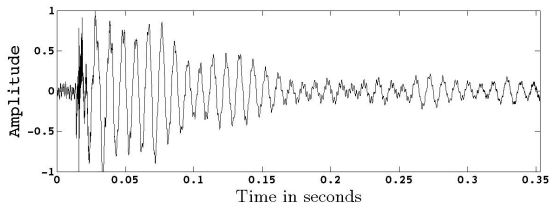


Figure 5: *dha(bayan+dayan)-bol*

It is evident from the Table that all the *tāla*-s except *rupak*, start with a *tālī-sam-bol* having both *dayan* and *bayan* component. Only *rupak* starts with a *khali-sam* and its *sam* does not contain any *bayan* component. *Bhājani tāla*, is often played with a variation for *bhajan, kirtan* or *qawwali* songs [ [10]], which makes the first(*tālī-sam*) and fourth *bol* as stressed. Although this fourth *bol* is not a *tālī vibhāga* boundary still it is rendered as stressed and it is

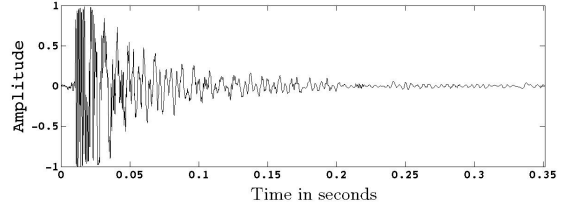


Figure 6: *ge(bayan)-bol*

to be noted here that this *bol* is played with *dayan* and *bayan* together. We have considered this *bhājani thekā* with first(*tālī-sam*) and fourth *bol* as stressed, because data in our experiment includes popular *bhajan* or devotional compositions.

For the *tāla*-s *dadra* and *kaharba* the number of pulses in the *thekā* and the *mātrā*-s are identical but for *rupak* and *bhājani* each *mātrā* is divided in to two equal duration *bol*-s. In effect *rupak* is a 7 *mātrā tāla* but has 14 pulses or *bol*-s and *bhājani* is 8 *mātrā tāla* but has 16 pulses or *bol*-s. *Bhājani thekā* in the Table 3 has half of its number of strokes as absent *bol*-s or rests(denoted by \*).

It should be noted that the standard *thekā* of *rupak* is *tin|tin|naIdhin|naIdhin|na*, but we have taken another *thekā* shown in the Table 3 for our experiment, Ref.[ Search Gurbani]. This *thekā* is normally followed for the semi-classical soundtracks and popular *hindi* songs. Moreover we got maximum number of annotated samples of polyphonic songs composed with this *thekā* for our validation process.

### 2.3 Lay or tempo

An important concept of rhythm in NIMS is *lay*, which governs the tempo or the rate of succession of *tāla*. The *lay* or tempo in NIMS can vary

### 3.1 Meter analysis in Western music

Table 3: Table of popular *thekā*-s of North Indian rhythms

<i>tāla</i>	Number of <i>mātrā</i> -s/ <i>vibhāga</i> in an <i>āvart</i>	<i>thekā</i>
<i>dadra</i>	3 I 3	<i>dha dhi naIna ti na</i>
<i>kaharba</i>	4 I 4	<i>dha ge na tiIna ke dhi na</i>
<i>rupak</i>	3 I 2 I 2	<i>tun na tun na ti teIdhin dhin dha dhaI dhin dhin dha dha</i>
<i>bhājani</i>	4 I 4	<i>dhin * na dhin * dhin na *Itin * na tin * tin na *</i>
<i>jhaptal</i>	2 I 3 I 2 I 3	<i>dhi naIdhi dhi naIti naIdhi dhi na</i>
<i>tintal</i>	4 I 4 I 4 I 4	<i>dha dhin dhin dhaIdha dhin dhin dhaIna tin tin naIte-Te dhin dhin dha</i>

among *ati-vilambit*(very slow), *vilambit*(slow), *madhya*(medium), *druta*(fast) to *ati-druta*(very fast). Tempo is expressed in beats per minute or BPM.

## 3 Past work

Although various rhythm analysis activities have been done for Western music, not much significant work has been done in the context of NIMS. Although the rhythmic aspect of Western music is much simpler in comparison to Indian one, to get the broad idea of the problem, our study includes the work on Western music. The extraction of percussive events from a polyphonic composition is an ongoing and challenging area of research. We have discussed existing drum separation approaches in Western music in Section 4, as they are relevant to our methodology. The existing works in meter analysis and beat-tracking for Western music, are discussed in the following section. Then similar discussion is made on existing rhythm analysis works in Indian music.

### 3.1 Meter analysis in Western music

In Western music beats have sharp attacks, fast decays and are uniformly repeated while in Middle Eastern and Indian music beats have irregular shapes. This is due the fact that bass instruments in these cultures are different from what is used in Western bands. By examining the distribution of Western meters, [11] found that they deviate from Gaussianity by a larger amount than non-western meters.

Works have been done by parsing MIDI data into rhythmic levels by [12]. But that can not deal real audio data. [13] attempted to encode the musical texts, notes into sequence of numbers and  $\pm$  signs. But it can be implemented only for the Western compositions for which the notation is available.

[14] showed multi-scale mechanism for the visualization of rhythm as rhythmogram. The rhythmogram provides a representation to the structure of spoken words and poems used, which is very different from polyphonic music but the model is implemented on synthesized binary pattern, strong and weak pulses, not from actual music composition.

[11] analysed the beat and rhythm information with a binary tree or trellis tree parsing depending on the length of the pauses in the input polyphonic signal. The approach relies on beat and rhythm information extracted from the raw data after low-pass filtering. It has been tested using music segments from various cultures.

[15], described methods for automatically locating points of significant change in music or audio, by analysing local self-similarity. This approach uses the signal to model itself, and thus does not rely on particular acoustic cues nor requires training.

[16] describes a method of estimating the musical meter jointly at three metrical levels of measure, beat and subdivision, which are referred to as *measure*, *tactus* and *tatum*, respectively. For the initial time-frequency analysis, a new technique is proposed which measures the degree of musical accent as a function of time at four different frequency ranges.

This is followed by a bank of comb filter resonators which extracts features for estimating the periods and phases of the three pulses. The features are processed by a probabilistic model which represents primitive musical knowledge and uses the low-level observations to perform joint estimation of the tatum, tactus, and measure pulses.

[17] addressed the problem of classifying polyphonic musical audio signals of Western music, by their meter, whether duple/triple. Their approach aimed to test the hypothesis that acoustic evidences for downbeats can be measured on signal low-level features by focusing especially on their temporal recurrences.

### 3.2 Beat-tracking in Western music

In the work of [[18]], a beat tracking system is described. A global tempo is first estimated. A transition cost function is constructed based on the global tempo. Then dynamic programming is used to find the best-scoring set of beat times that reflect the tempo.

In [ [19]] a real-time beat tracking system is designed, that processes audio signals that contain sounds of various instruments. The main feature of this work is to make context-dependent decisions by leveraging musical knowledge represented as drum patterns.

In [[20]], the envelope of the music signal is extracted at different frequency bands. The envelope information is then used to extract and track the strokes/pulses.

To classify percussive events embedded in continuous audio streams, [21] relied on a method based on automatic adaptation of the analysis frame size to the smallest metrical pulse, called the *tick*.

[22] has created a system named BeatRoot for automatic tracking and annotation of strokes for a wide range of musical styles. [23] proposed a context dependent beat tracking method which handles varying tempos by providing a two state model. The first state tracks the tempo changes, then the second maintains contextual continuity within a single tempo hypothesis. [24] proposed a data driven ap-

proach for beat tracking using context-aware neural networks.

### 3.3 Rhythm analysis in Indian Music

The concepts of *tāla* and its elements are briefed in Section 2. For Indian percussive systems, strokes are of irregular nature and mostly are not of same strength. In comparison with Western music, not much significant work in rhythm analysis in Indian music, has been reported so far.

The system proposed in [[25]] uses Probabilistic Latent Component Analysis method to extract *tablā* signals from polyphonic *tablā* solo. Then each separated signal is re-synthesized in each layer and the music is regenerated in *quida*(improvisation of *tablā* performances) model. The work is restricted to *tablā* solo performances where the *tablā* signal is the most significant component, and not for polyphonic compositions where *tablā* is one of the percussive accompaniment.

In [ [26]] the work of [ [27]] is extended. The methodology for meter detection in Western music is applied for Indian music. A two-stage comb filter-based approach, originally proposed for double/triple meter estimation, is extended to a septuple meter (such as 7/8 time-signature). But this model does not conform to the *tāla* system of Indian music.

[ [28]] explored various techniques for rhythm analysis based on the Indian percussive instruments. An effort is made to extract the *tablā* component from a polyphonic music by estimating the onset candidates with respect to the annotated onsets. Various existing segmentation techniques for annotating polyphonic *tablā* compositions, were also tried. But the goal of automatic detection of *tāla* in Indian music did not succeed.

Some work has been done to detect a few important parameters like *mātrā*, tempo by first using signal level properties and then using cyclic properties of *tāla*. The work in[[29]] for *mātrā* and tempo detection for NIMS *tāla*-s, is based on the extraction of beat patterns that get repeated in the signal. Such pattern is identified by processing the amplitude envelope of a music signal. *Mātrā* and tempo are detected from the extracted beat pattern. This work is extended



to handle different renderings of *thekā*-s comprised of single and composite *bol*-s. In this work[[30]] *bol* duration histogram is plotted from the *beat signal* and the highest occurring *bol*-duration is taken as the actual *bol*-duration of the input *beat signal*. The above methodology has been tested on electronic *tablā* signal. In case of the real *tablā* signal it is impossible to maintain consistency in terms of the periodicity of the *bol*-s or *beat*-s played by a human. To resolve this issue the work is further extended and modified to handle real *tablā* signal in[ [31]] and this comparison is carried out for the entire *beat signal* and a weight-age or the probability of the experimental signal being played according to certain *tāla*-s of NIMS, is calculated. The *mātrā* of the *tāla* for which this weight-age is maximum, is confirmed as the *mātrā* of the input signal. This methodology was tested with real-*tablā*-solo performance recordings. In recent times experiments and analysis have been done with non-stationary, nonlinear aspects of NIMS in [[32];[33]].

It is evident from the study that rhythm analysis in NIMS, focusing on *tāla* rendered with *tablā*, the most popular North Indian percussive instrument, is a wide area of research. In our work, an approach for rhythm analysis is proposed, which is built around the theory of *tāla* in NIMS.

## 4 Proposed Methodology

As it has been already discussed that there is a frequency overlap between *tablā*(*bayan* and *dayan*) with voice and other instruments in a polyphonic composition, accurate extraction of *tablā* signal from the mixed signal by following the source separation techniques based on frequency based filtering[ [34]; [35]], has not been very successful. Also these source separation methods lead to substantial loss of information or sometimes addition of unwanted noise. It has motivated us to look for an alternate approach. Here we have adopted a four-step methodology which is detailed out in following sections.

1. First we have processed the polyphonic input signal by partially adopting a filter-based separation technique. In doing so we are able to separate out the *bayan*-stroke-signal which would

consist of the only *bayan*-strokes and also the *bayan*-components of *bayan*+*dayan*-strokes.

2. Then we have processed the entire polyphonic signal and generated a *peak*-signal, which comprises of all the emphasized *peak*-s generated out of *tablā* and other percussive instruments played in the polyphonic composition of a specific *tāla*. *Peak*-signal would contain the *peak*-s of *bayan*-stroke-signal, and also the emphasized *peak*-s of *tablā*(i.e. only *dayan*-strokes and *bayan*+*dayan*-strokes). If other percussive instruments played, then in addition to the above, the *peak*-signal would also contain emphasized *peak*-s generated out of them
3. Next we have refined the *bayan*-stroke-signal and the *peak*-signal.
4. Lastly we propose to generate a co-occurrence matrix from both kinds of signals and exploit domain specific information of *tablā* and *tāla* theory, to detect the *tāla* and tempo of the input polyphonic signal.

Overall flow of the process starting from generation of *bayan*-stroke-signal to the final co-occurrence matrix is shown in the Figure 7, for a test clip composed in *dadra tāla*. The process of generating final *bayan*-stroke-signal[sub-figure 3] is described in the Section 4.1 and final *peak*-signal[sub-figure 4] is described in Section 4.2, Figure 8.

### 4.1 Separation of bayan-stroke-signal

In Western music drum is one of the mostly used percussive instruments. Extraction of drum signal is a part of applications like identification of type of drums, re-synthesizing the drum track of a composite music signal. Existing approaches for drum signal separation are described in Section 4.1.1 and our method of extracting *bayan*-stroke-signal is described in Section 4.1.2.

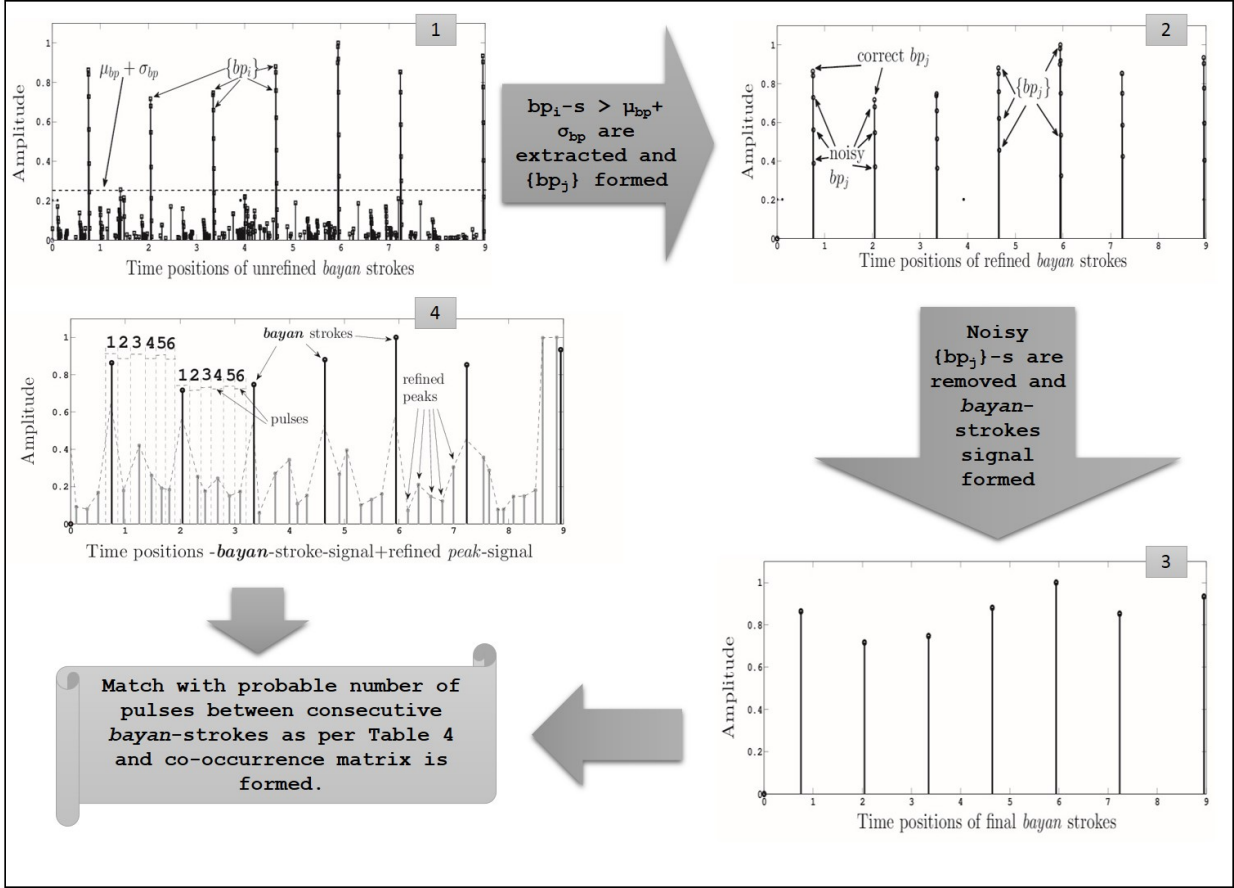


Figure 7: Process flow from generation of *bayan*-stroke-signal to the co-occurrence matrix, for a polyphonic composition

#### 4.1.1 Drum separation approaches in Western music

1. **Blind Source Separation method:** Christian Uhle, Christian Dittmar, Thomas Sporer [34] proposed a method based on Independent Subspace Analysis method to separate drum tracks from popular Western music data. In the work of Helén and Virtanen [35], a method has been proposed for the separation of pitched musical instruments and drums from polyphonic music. Non-negative Matrix Factorization (NMF) is used to analyze the spectrogram and thereby

to separate the components.

2. **Match and adapt method:** The methodology defines the template(temporal as stated in [36] or spectral as stated in [37]), of drum sound, then searches for similar patterns in the signal. The template is updated and also improved in accordance with those observations of patterns. This set of methods extracts as well as transcribes drum component.
3. **Discriminative model** This approach is built upon a discriminative model between harmonic and drums sounds. In the work of Gillet and

Richard[ [5]], music signal is split into several frequency bands, the for each band the signal is decomposed into deterministic and stochastic part. The stochastic part is used to detect drum events and to re-synthesize a drum track. Possible applications include drum transcription, remixing, and independent processing of the rhythmic and melodic components of music signals. Ono et al.[ [6]] have proposed a method that exploits the differences in the spectrograms of harmonic and percussive components.

#### 4.1.2 Our approach

Our approach for separating out *bayan-stroke-signal* falls in the Discriminative model group for separating out harmonic and drums sounds, among the three categories described above.

To extract the *bayan-stroke-signal* we have used ERB or Equivalent Rectangular Bandwidth filter banks. The ERB is a measure used in psychoacoustics, which gives an approximation to the bandwidths of the filters in human auditory system [ [38]]. Alghoniemy and Tewfik[ [11]] have done empirical study of western drums and confirmed that they could extract the bass drum sequences by filtering the music signal with a narrow bandpass filter. Ranade[ [39]] confirmed the same range(60-200Hz) for the bass drum or *bayan* of Indian *tablā*. If we take 20 ERB filter banks to extract different components like voice, *tablā* and other accompaniments from the polyphonic signal with sampling rate of 44100Hz, the central frequency of the second bank comes out to be around 130Hz and the bandwidth of around 60-200Hz. It has been observed from the spectral and wavelet analysis of the different type of *bayan-bol*-s described in the Section 2.2 and Table 2, that their frequency ranges around the same central frequency and bandwidth. So we have divided the input polyphonic signal sampled at 44100Hz, into 20 ERB filter banks and extracted the second bank for constructing the *bayan-stroke-signal*. We have used MIRtoolbox[ [40]] to extract this frequency range from ERB filter banks.

As described in the Section 2.1, most of the *tālā*-s in NIMS start with a highly stressed *tālī-sam-bol* played with *bayan* or *bayan* and *dayan* com-

bined. Moreover *tālī vibhāga* boundaries are also usually stressed. Thus extracted *bayan-stroke-signal* would mostly consist of *peak*-s generated from *tālī-sam*-s and *tālī-vibhāga* boundaries. There might be presence of other high-strength-*peak*-s generated out of *bol*-s having *bayan* component, other than *tālī-sam* and *tālī-vibhāga* boundaries, for compositions with slow(20BPM) or very slow(10BPM) tempo. But for popular, semi-classical and filmy North Indian compositions, the tempo is moderate to fast. These compositions mostly do not have the emphasized, high strength *bayan-peak*-s other than *tālī-sam*, *tālī-vibhāga* boundaries in the *bayan-stroke-signal*. Even if these additional *bol*-s having *bayan*-component, produce *peak*-s in the *bayan-stroke-signal*, their strength is much weaker, compared to *tālī-sam* or *tālī-vibhāga* boundaries.

The process below is followed to remove these additional *bol*-s having *bayan* component, from the *bayan-stroke-signal*.

- Let  $\{bp_i\}$  be the set of *peak*-s in the *bayan-strokes-signal* extracted from a polyphonic song-signal. Please note the Figure 7(1), where  $bp_i$ -s for a particular polyphonic sample of *dadra tāla* are shown.
- We calculate the *mean*- $\mu_{bp}$  and *standard deviation*- $\sigma_{bp}$  for the set  $\{bp_i\}$ . In the Figure 7(1), the corresponding value of  $\mu_{bp} + \sigma_{bp}$  is shown. It should be noted there are lots of noisy *peak*-s with magnitude less than  $\mu_{bp} + \sigma_{bp}$ .
- $\{bp_j\}$  is obtained as a subset of  $\{bp_i\}$  after selecting the high-strength *bayan-strokes* greater than  $\mu_{bp} + \sigma_{bp}$ .
- $\{bp_j\}$  is the set of strokes mostly containing *tālī-sam*-s and *tālī-vibhāga* boundaries having *bayan*-component, for a polyphonic composition. In the Figure 7(2), the corresponding time positions of  $\{bp_j\}$  are shown.
- However there would always be some noisy *peak*-s in  $\{bp_j\}$ , hence a further refinement is done as per the method in Section 4.3 and finally the refined *bayan-stroke-signal* is shown in the Figure 7(3).

## 4.2 Peak-signal:

From the input polyphonic signal waveform, differential envelope is generated after applying half-wave rectifier. The *peak*-s are extracted from the amplitude envelope of the signal, by calculating the local maxima-s. Local maxima-s are defined as the *peak*-s in the envelope with amplitude higher than their adjoining local minima-s by a default threshold quantity of  $d_f \times l_{max}$ , where,  $l_{max}$  is the maximum amplitude point of the envelope. Here we have taken default minimum value for  $d_f$  in the MIRtoolbox[ [40]], which would extract almost all the *peak*-s in the input envelope. Each *peak* in the *peak*-signal, is mainly generated out of *tablā* and other percussive instruments played in the polyphonic composition. These *peak*-s are supposed to be more stressed than other melodic instruments and vocals rendered with comparatively more steady range of energies(without much ups and down, hence unable to produce high-energy *peak*-s). Figure 8(1) shows all the *peak*-s along with the positions of the *bayān*-strokes of the *bayān*-stroke-signal in **bold**, for the same test clip of the Figure 7. The *bayān*-stroke-signal has been generated as per process in Section 4.1.

## 4.3 Refinement of *bayān* and *peak*-signal:

There may be multiple percussive instruments and also human voice in a polyphonic composition. There is a tendency to stress more at the *tālī-sam* and *tālī-vibhāga* boundaries by the performer, while singing along with the *tāla*. Hence for polyphonic compositions, other percussive instruments and human voice also generate *peak*-s in the *bayān*-stroke-signal, coinciding with *bayān*-strokes.

*Peak*-signal for polyphonic signal also consists of *peak*-s produced by *tablā*, percussive instruments(if present) and human voice. For both *bayān*-stroke and *peak* signals, these *peak*-s should coincide with respect to their positions in *X*-axis or time of their occurrences. But among them the *peak*-s generated out of *tablā* or the drum instrument here, are usually of higher strength. Using this theory we go for refinement of both *bayān*-stroke-signal and *peak*-

signal to retain the most of the *peak*-s generated from *tablā*, and discard other kinds of percussive *peak*-s. It has been observed that most of the popular *hindī* compositions(classical or semi-classical) have tempo much less than 600 beats per minute[ Rhythm Taal]. Thereby minimum beat interval or gap between consecutive *tablā* strokes in these compositions, is much more than  $60/600 = 0.1\text{sec}$ .

Hence both the *bayān*-stroke-signal and *peak*-signal are divided into 0.1 sec duration windows along *X*-axis. For each window the *peak* having highest strength is retained as correct *bayān*-stroke(in *bayān*-stroke-signal) or any other valid *tablā peak*(in *peak*-signal), and rest of the *peak*-s in each window is dropped. This way the noisy *peak*-s are removed and final *bayān*-stroke-signal and *peak*-signal are obtained. Figure 8(2) shows the final, high-strength and refined *peak*-signal, with the positions of the *bayān*-strokes of the refined *bayān*-stroke-signal in **bold**. The same final *peak*-signal is referred in Figure 7(4). Figure 9 is the magnified version of Figure 8(2), 7(4).

## 4.4 Analysis based on *tablā* and *tāla* theory

The refined *peak*-signal for the same clip in *dadra tāla* is shown in Figure 9. As per the *thekā* of *dadra* in Table 3, apart from the *sam-dha* there is no other *tālī-vibhāga* boundaries, hence its final *bayān*-stroke-signal should contain these *sam*-s only.

- **Pulse:** Here pulse is defined as the amplitude envelope of a stroke whose *peak* is extracted in the *peak*-signal.
- **Peak:** It should be noted here that, a *peak* in the refined *peak*-signal(from Section 4.3), is the highest point of an amplitude envelope formed for a pulse. Hence *peak* is actually the mid-point of the pulse duration in seconds along the *X*-axis.

For the test clip of *dadra tāla*, the *peak*-s and the pulses are elaborated in Figure 9. Here we can see there are 5 *peak*-s and 6 pulses in between two consecutive *bayān* stroke.

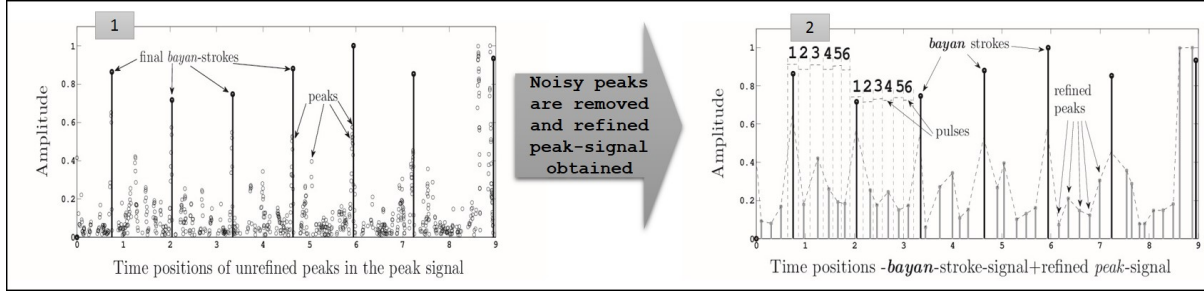


Figure 8: Percussive *peak*-s along with *bayan*-strokes in bold line, for a polyphonic clip of *dadra tāla*.

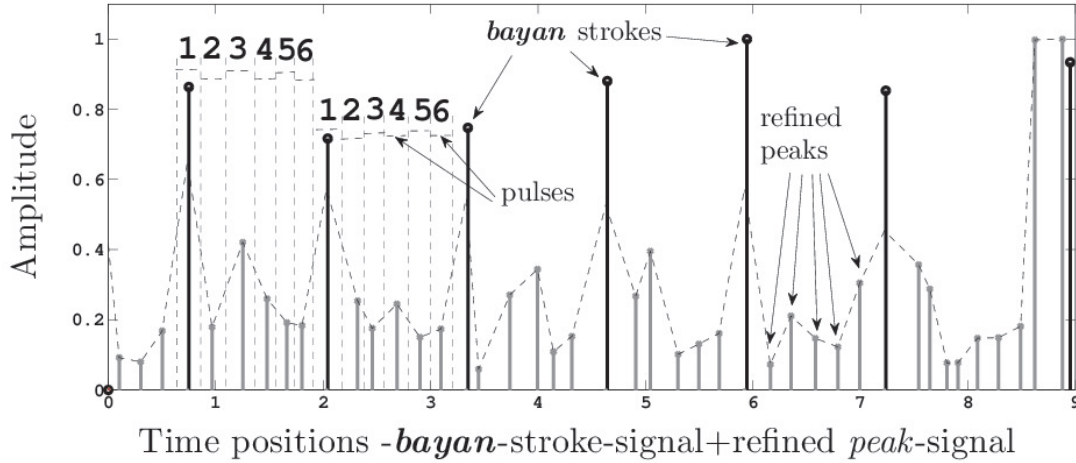


Figure 9: Magnified version of Figure 8(2) showing details of *peak*-signal.

The method of *tāla* detection based on *tablā* and *tāla* theory is explained in the following sections.

#### 4.4.1 First level analysis of pulse pattern

As per the theories explained in Section 2.1 and 2.2, we have extended the Table 3 and created another Table 4. Here the first column describes number of probable pulses in between two *bayan* strokes, as per the theories. For example, for *dadra tāla*, number of pulses in between a *dha-bol/sam* of an *āvarṭ* and the *dha-bol/sam* of the next *āvarṭ* should theoretically be 6 as per the *dadra thekā* in the Table 4. This 6 – 6 pattern of number of pulses should continue along the progression of the composition. The

third column describes the *thekā*-s corresponding to the pulse pattern, with *tālī-sam*-s and *tālī-vibhāga*-boundary-*bol*-s in **bold** as per the theory explained in Section 2.1 and 2.2. The pipes in **bold** represent the start of *vibhāga*-boundaries within single *āvarṭ*. *Āvarṭ*-sequences are shown and for each *thekā*, an *āvarṭ* and the starting *bol* of next *āvarṭ* is given, to indicate the progression of *tāla*-s.

It is to be noted that *bhājani thekā* has half of its number of strokes as rests. Other percussive instrument and vocal emphasis would normally generate *peak*-s of moderate strength for the time positions of these strokes in an *āvarṭ*, especially for the genres of our experimental compositions. Hence, here *bhājani* is considered as *tāla* with 16 pulses/*āvarṭ*.

It should be noted that for *tāla*-s like *bhajani* and *rupak*, there are two sets of probable no of pulses. For example for *rupak* there is both  $4 - 10$  and  $10 - 4$ . This is because we are calculating number of pulses for the consecutive *āvart* along the progression of the song. So suppose if we start from *āvart*<sup>1</sup>, the second *vibhāga*-boundary-*bol* has *bayān* component and it will generate a *peak* in the *bayān*-stroke-signal. Next *peak* in the *bayān*-stroke-signal would be the third *vibhāga*-boundary-*bol*. So in between them (*Idhin dhin dha dhaIdhin*) there would be 3 *peak*-s and 4 pulses. Next *peak* in the *bayān*-stroke-signal would be the second *vibhāga*-boundary-*bol* of the *āvart*<sup>2</sup> and evidently there would be 9 *peak*-s and 10 pulses between second and third *peak*-s in *bayān*-stroke-signal (*dhin dhin dha dha<sup>2</sup>tun na tun na ti teIdhin*). It gives rise to pulse pattern of  $4 - 10$ , considering first, second and third *peak*-s in *bayān*-stroke-signal. Now if we move on and consider second, third and fourth *bayān*-*peak*-s, the detected pulse pattern should be  $10 - 4$ , then again  $4 - 10$  and it will go on for the entire progression of the song. So both  $4 - 10$  and  $10 - 4$  would signify *rupak tāla* with same set of stressed *bol*-s in the *thekā*.

#### 4.4.2 Extended analysis of pulse pattern

It should be noted that, in *vilambit* compositions there may be additional filler strokes apart from the basic *thekā*, which lead to additional significant *peak*-s in both the *bayān*-stroke-signal and the *peak*-signal. In *druta* compositions often several *thekā* strokes are skipped and only *vibhāga*-s are stressed.

Table 4 shows the elementary set of probable pulses in between consecutive *bayān* strokes for clear understanding of the concept. To keep room for variations and improvisations of the *thekā* that are allowed within a specific *tāla*, we have extended this set in our experiment. There we have included all the probable patterns of pulse-counts, by considering the probability of additional *bayān* or *bayān+dayān*-strokes in a *thekā* to be stressed. We are assuming that apart from the mandatory *tālī-sam* and *tālī-vibhāga* boundaries, any other *bol*-s having *bayān* component may be stressed and produce a *peak* in the *bayān*-stroke-signal.

Here we have shown all the probabilities (including basic and extended) for *dadra tāla* in Table 5, as an example. Here in this *dadra-thekā* apart from the *tālī-sam-bol* which is *dha*, of an *āvart*, the very next *bol* is *dhi* also has *bayān*-component. So apart from mandatory *sam* this *bol* can also be stressed and give rise to pulse pattern of  $1 - 5, 5 - 1$ . Similarly for rest of the *tāla*-s, all probable combinations of number of pulses are calculated.

#### 4.4.3 Generation of co-occurrence matrix and detection of *tāla*

For each test sample, we have taken the refined version of *bayān*-stroke-signal (generated as per the method in Section 4.1 and then refined as per the method in 4.3), *peak*-signal (generated as per the method in Section 4.2 and refined as per the method in 4.3) and the co-occurrence matrix is formed and *tāla* is detected as per the following steps. Here co-occurrence matrix displays the distribution of co-occurring pulse-counts along the sequence of the *bayān*-stroke-intervals, in a matrix format. The Figure 7 shows the overall process flow of generation of co-occurrence matrix from refined *bayān*-stroke-signal and *peak*-signal.

1. We extract the time positions of the *peak*-s of the refined *peak*-signal and the *bayān*-stroke-signal along the *X*-axis or time axis.
2. Then we calculate the count of *peak*-signal-pulses occurring in each of the time intervals formed by consecutive *peak*-s of *bayān*-stroke-signal. Here we denote the series of pulse-counts calculated for a test-sample as  $(pc_1, pc_2, \dots, pc_k)$ , where  $k = (\text{number of } bayān\text{-strokes} - 1)$ . For example, we can see in the Figure 9, there are 5 *peak*-s between two consecutive *bayān*-strokes the number of pulses are 6 or  $pc_1 = 6$ . Similarly, we calculate the rest of the  $pc_i$ -s.
3. Then we form a  $16 \times 16$  co-occurrence matrix (having 16 rows and 16 column/row) and initialize all of its elements with zero. Maximum dimension of the matrix is taken as 16 because for our test data there can be maximum of

#### 4.4 Analysis based on *tablā* and *tāla* theory

Table 4: Probable number of pulses in between consecutive *bayan*-strokes, corresponding *thekā*-s and the *tālā*-s

Number of probable pulses between consecutive <i>bayan</i> -strokes	<i>Tāla</i> -s	Corresponding <i>thekā</i> -s with <i>āvart</i> -sequences
6-6	<i>dadra</i>	<sup>1</sup> <i> dha dhi naIna ti na<sup>2</sup> dha..</i>
8-8	<i>kaharba</i>	<sup>1</sup> <i> dha ge na tiIna ke dhi na<sup>2</sup> dha..</i>
4-10,10-4	<i>rupak</i>	<sup>1</sup> <i> tun na tun na ti teIdhin dhin dha dhaIdhin dhin dha dha<sup>2</sup> tun na..</i>
14-14	<i>rupak</i>	<sup>1</sup> <i> tun na tun na ti teIdhin dhin dha dhaI dhin dhin dha dha<sup>2</sup> tun na..</i>
3-13,13-3	<i>bhajani</i>	<sup>1</sup> <i> dhin * na dhin * dhin na *Itin * ta tin * tin ta *<sup>2</sup> dhin *..</i>
16-16	<i>bhajani</i>	<sup>1</sup> <i> dhin * na dhin * dhin na *Itin * ta tin * tin ta *<sup>2</sup> dhin *..</i>

Table 5: Probable number of pulses in between consecutive *bayan* strokes in the *thekā* for *dadra tāla*

Number of probable pulses between consecutive <i>bayan</i> -strokes	Corresponding <i>thekā</i> -s with <i>āvart</i> -sequences
6-6	<sup>1</sup> <i> dha dhi naIna ti na<sup>2</sup> dha..</i>
1-5,5-1	<sup>1</sup> <i> dha dhi naIna ti na<sup>2</sup> dha dhi..</i>

- 16 number of pulses between consecutive *bayan*-strokes[Ref Table 4].
- Then we fill up the co-occurrence matrix by occurrence of each pair of pulse-counts between the consecutive intervals in the *bayan*-stroke-signal formed for the whole test sample. We denote each consecutive pair as  $pc_i, pc_{i+1}$ , where  $pc_i \in (1, 2, \dots, 16)$  and  $pc_{i+1} \in (1, 2, \dots, 16)$ . For example if the number of pulses between first and the second *peak*-s in the *bayan*-stroke-signal is 4 and the same between the second and the third is 6. So  $pc_1, pc_2$  becomes 4, 6 and we add 1 to the matrix element of fourth row and sixth column, which now becomes 1 from initialized zero value. Then we check the same between third and fourth *peak* which is suppose 6, hence  $pc_2, pc_3$  becomes 6, 6 and 1 is added to the matrix element of sixth row and sixth column, making it 1 from zero.
  - We traverse the whole *peak*-signal and the *bayan*-stroke-signal and update the matrix. Each cell of the matrix contain the occurrence of a particular pulse count pattern in consecutive intervals in *bayan*-stroke-signal.
  - Finally we extract the row and column index of the cell in the matrix containing the maximum value. This row and column index is the most occurring pattern of pulse counts in consecutive intervals in *bayan*-stroke-signal. Here this row-column index of the matrix is denoted by  $[pcmax_1, pcmax_2]$ .  
The co-occurrence matrix for a test sample, is shown in Table 6 where we can see 10 as the maximum value in 6<sup>th</sup> row and 6<sup>th</sup> column i.e.  $[pcmax_1 = 6, pcmax_2 = 6]$ .
  - Then the  $[pcmax_1, pcmax_2]$  is matched against the first column of the Table 4 and also the rules

Table 6: Co-occurrence matrix formed for a composition played in *dadra tāla*

	1	2	3	4	5	6	7	...
1	0	0	0	0	3	0	0	...
2	0	0	0	0	0	0	0	...
3	0	0	0	0	0	0	0	...
4	0	0	0	0	0	0	0	...
5	1	0	0	0	0	0	0	...
6	0	0	0	0	0	10	0	...
7	0	0	0	0	0	0	0	...
...	..	..	..	..	..	..	..	...

defined in Section 4.4.2. Accordingly *tāla* is decided from its second column. For the test sample for which the co-occurrence matrix is shown in the Table 6,  $pcmax_1 = 6$  and  $pcmax_2 = 6$  are extracted and it is exactly matched with 6 – 6 pattern for number of probable pulses between consecutive *bayān*-strokes, hence it is detected as of *dadra tāla*.

- While matching occurrence pattern of *peak*-s between consecutive *bayān-peak*-s, apart from the rules explained in Section 4.4.1 and 4.4.2, a tolerance of  $\pm 1$  is considered. For example, if for a test clip we get 6 – 6 number of *peak*-s between consecutive *bayān* duration in the *bayān*-stroke-signal, we detect it as of *dadra tāla*. But even if we get 5 – 6, 6 – 5, then also detect it of *dadra*. This way we are considering human errors within a narrow range of tolerance.

#### 4.4.4 Detection of tempo

Tempo or *lay* is detected in terms of pulses per minute as per the method below.

- Once we detect  $[pcmax_1, pcmax_2]$ , we get the *tāla* as per the process described in Section 4.4.3. Then we collect all the consecutive pair of *bayān* durations having  $pcmax_1$  and  $pcmax_2$  number of pulses for the whole composition. In the Figure 9, we can see that for this particular *dadra* clip there are 6 number of pulses in the intervals

between first two *bayān*-strokes and also second, third *bayān*-strokes.

Suppose these *bayān* durations are denoted by  $(bd1_1, bd1_2, \dots, bd1_n)$  having  $pcmax_1$  number of pulses and  $(bd2_1, bd2_2, \dots, bd2_n)$  having  $pcmax_2$  number of pulses, where  $n$  is the value in the cell of co-occurrence matrix having row index  $pcmax_1$  and column index  $pcmax_2$ . It basically means that  $pcmax_1, pcmax_2$  pair has occurred for  $n$  no of times in the co-occurrence matrix and also in the whole test composition.

- Then all these *bayān* durations are added. We denote that by  $bayān_{dur} = \sum_{i=1}^n bd1_i + \sum_{i=1}^n bd2_i$ . Total number of pulses in these durations are  $count_{pulse} = n * (pcmax_1 + pcmax_2)$ .  $bayān_{dur}$  is measured in second.
- The average duration of a pulse in the composition is calculated as  $pulse_{dur} = \frac{bayān_{dur}}{count_{pulse}}$  in second.
- Then the tempo is calculated as  $tempo = \frac{60}{pulse_{dur}}$  in beats per minute.

## 5 Experimental details

### 5.1 Data description

We have experimented with a number of polyphonic composition of NIMS vocal songs rendered with four popular *thekā*-s of the *tāla*-s, as described in Table 4. The test compositions are from *bhajan* or devotional, semi-classical and film-music genres, having *tablā* and other percussive instruments as accompaniments. The film-music and semi-classical genres are chosen because they mostly maintain similar structures with minimal improvisation and regular tempos as far as rhythm of the compositions is concerned. Hence this test dataset should be suitable for finalizing the elementary layer of the *tāla*-detection system of NIMS.

The *tāla*-s considered are *dadra*, *kaharba*, *rupak*, *bhājani*, as most of the songs in above genres are composed in these *tāla*-s. Also we got maximum number of annotated samples of polyphonic songs



composed with these *tāla*-s, which helped in rigorous testing and validation process. Also as these *tāla*-s have unique *mātra*-s and they would produce mostly unique number of *peak*-s between consecutive *bayān*-strokes, so experimenting with sufficient number of test samples composed in these *tāla*-s enabled us to validate the applicability of the initial version of our model.

The annotated list of *tāla*-wise songs are obtained from [Sound of India and FILM SONGS IN VARIOUS TALS] and also from the albums The Best Of Anup Jalota(Universal Music India Pvt Ltd), Bhanjanjali vol 2(Venus), Bhajans(Universal Music India Pvt Ltd), Songs Of The Seasons Vol 2(Shobha Gurtu). The annotations are validated by renowned musician Subhranil Sarkar. All the song clips are in single channel .wav format sampled at 44100Hz and are annotated. The clips are of 60 second duration. The tempo ranges from *madhya* to *ati-druta* tempo. The tempo of the input samples were calculated by manual tapping by expert musicians and this calculated tempo was assumed to be our benchmark for validation. The detailed description of the data used is shown in Table 7. The tempo is uniformly maintained for the input sound samples of the experiment. The data reflects variation in terms of genre, types of instruments and voices in the composition, tempo and *mātrā* of the compositions.

## 5.2 Results

Table 8 shows the confusion matrix for *tāla* detection. Here the column *none* signifies that the *tāla* of the input clip is NOT detected as any of the input *tāla*-s(*dadra*, *kaharba*, *rupak*, *bhājani*). There is an incorrect detection between the pair of *kaharba* and *bhājani*. Few *bhājani* samples have been detected as *kaharba* and vice-versa. For a specific *laggi* or variation of *bhājani tāla* Bhajan taal, a composition might turn out to be with 8 – 8 pulse pattern where  $pcmax_1 = 8$ ,  $pcmax_2 = 8$ . In this case it would be detected as *kaharba* as per our method. However, this error is not so severe as technically *bhājani* is a variation of *kaharba* [9].

Also as per the Table 4 theoretically 8 – 8 pulse pattern is for *kaharba* and 16 – 16 is for *bhājani*, i.e.

pattern for *bhājani* is exactly twice of *kaharba*. For some rare cases of manual error, while playing *tablā* in *kaharba*, the *tablā*-expert might make some *sam*-s less stressed and these *sam*-s might fail to generate *bayān-peak*-s in the refined *bayān*-stroke-signal. In these cases *kaharba* might produce 16 – 16 pulse pattern and would be detected as *bhājani*. However this is much rare as theoretically for any *tablā* composition the *tālī-bol-sam* must be stressed.

Table 8: Confusion matrix for *tāla* detection for the clips (all figures in %)

	<i>dadra</i>	<i>kaharba</i>	<i>bhājani</i>	<i>rupak</i>	<i>none</i>
<i>dadra</i>	80.85	6.38	06.38	4.26	2.13
<i>kaharba</i>	4.17	81.25	8.33	2.08	4.16
<i>bhājani</i>	3.57	12.50	78.57	3.57	1.79
<i>rupak</i>	3.50	4.50	4.00	86.00	2.00

Table 9 shows the performance of proposed methodology in detecting tempo for different compositions. In judging the correctness of tempo, a tolerance of  $\pm 5\%$  is considered.

Overall *tāla* and tempo detection performance is shown in Table 10. It is clear that the proposed methodology performs satisfactorily and that too with wide variety of data.

## 6 Conclusion

1. This paper presents the results of analysis of *tablā* signal of North Indian polyphonic composi-

Table 9: Performance of tempo detection (all figures in %)

<i>tāla</i>	Correct detection
<i>dadra</i>	80.85
<i>kaharba</i>	77.08
<i>bhājani</i>	80.35
<i>rupak</i>	76.00

Table 7: Description of data

<i>tāla</i>	<i>mātrā</i>	Tempo range(in BPM)	No of clips
<i>dadra</i>	6	140-320	65
<i>kaharba</i>	8	220-400	65
<i>bhājani</i>	8	300-360	65
<i>rupak</i>	7	240-375	65

Table 10: Gross performance of *tāla* and tempo detection (all figures in %)

Average performance	
<i>mātrā</i> detection	Tempo detection
81.59	78.60

tion, with the help of new technique by extracting the *bayan* signal.

2. The justification of using *bayan* signal as the guiding signal in case of North Indian polyphonic music and detecting *tāla* using the parameters of NIMS rhythm, has been clearly discussed.
3. A large number of polyphonic music samples from *hindi* vocal songs from *bhajan* or devotional, semi-classical and filmy genres were analyzed for studying the effectiveness of the proposed new method.
4. The experimental result of the present investigation clearly supports the pronounced effectiveness of the proposed technique.
5. We would extend this methodology for studying other features(both stationary and non-stationary) of the all the relevant *tāla*-s of NIMS and designing an automated rhythm-wise categorization system for polyphonic compositions. This system may be used for content-based music retrieval in NIMS. Also a potential tool in the area of music research and training is expected to come out of it.

Limitations of the method is that it can not distinguish between *tāla*-s of same *mātrā*. For example *deepchandi* and *dhamar tāla*-s have 14 number of *mātrā*-s, textitbol-s and beats in a cycle. We plan to extend this elementary model of *tāla*-detection system for all the NIMS *tāla*-s, by including other properties like timbral information and nonlinear properties of different kinds of *tablā* strokes/*bol*-s. We may also attempt to transcript the *tāla-bol*-s in a polyphonic composition. This extended version of the model may address the NIMS *tāla*-s which share same *mātrā* and also have variety of *lay*-s.

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